# Magnets at Fermilab

## Physics for Everyone

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(Most photos courtesy of VMS and TD Process Engineering)

Fermilab

Fermi Research Alliance

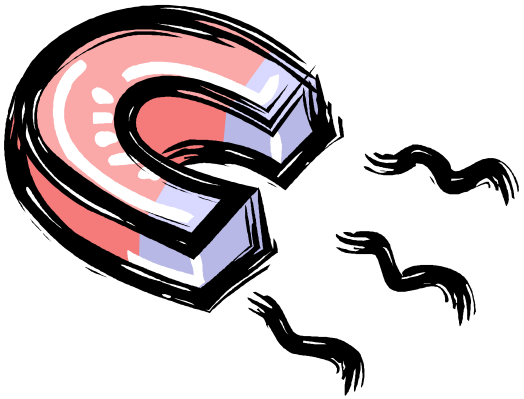
Office of Science / U.S. Department of Energy

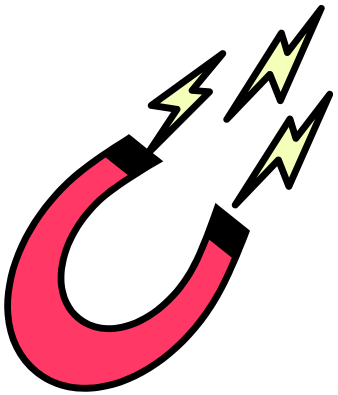
# What is the difference between a refrigerator magnet and a Fermilab magnet?

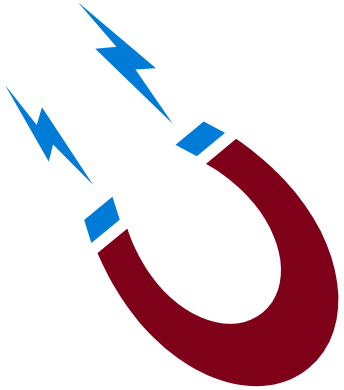
- A refrigerator magnet binds articles

- A Fermilab magnet bends particles

# What is a Magnet?

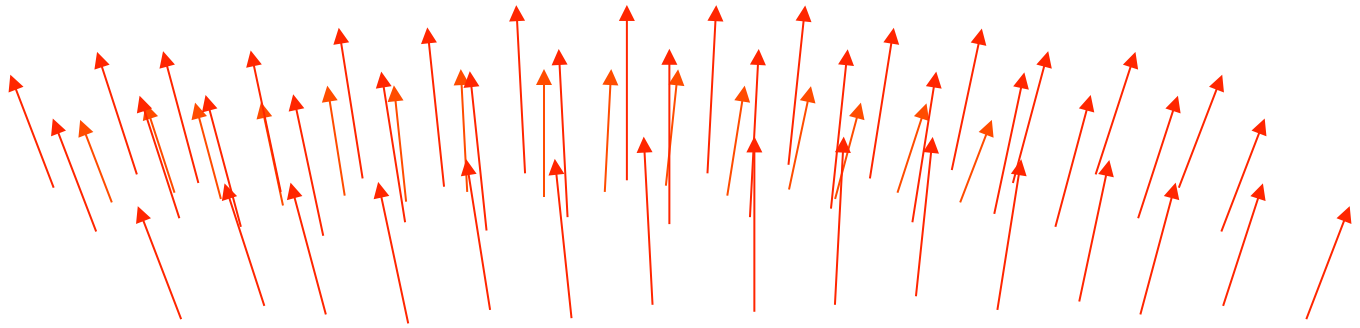




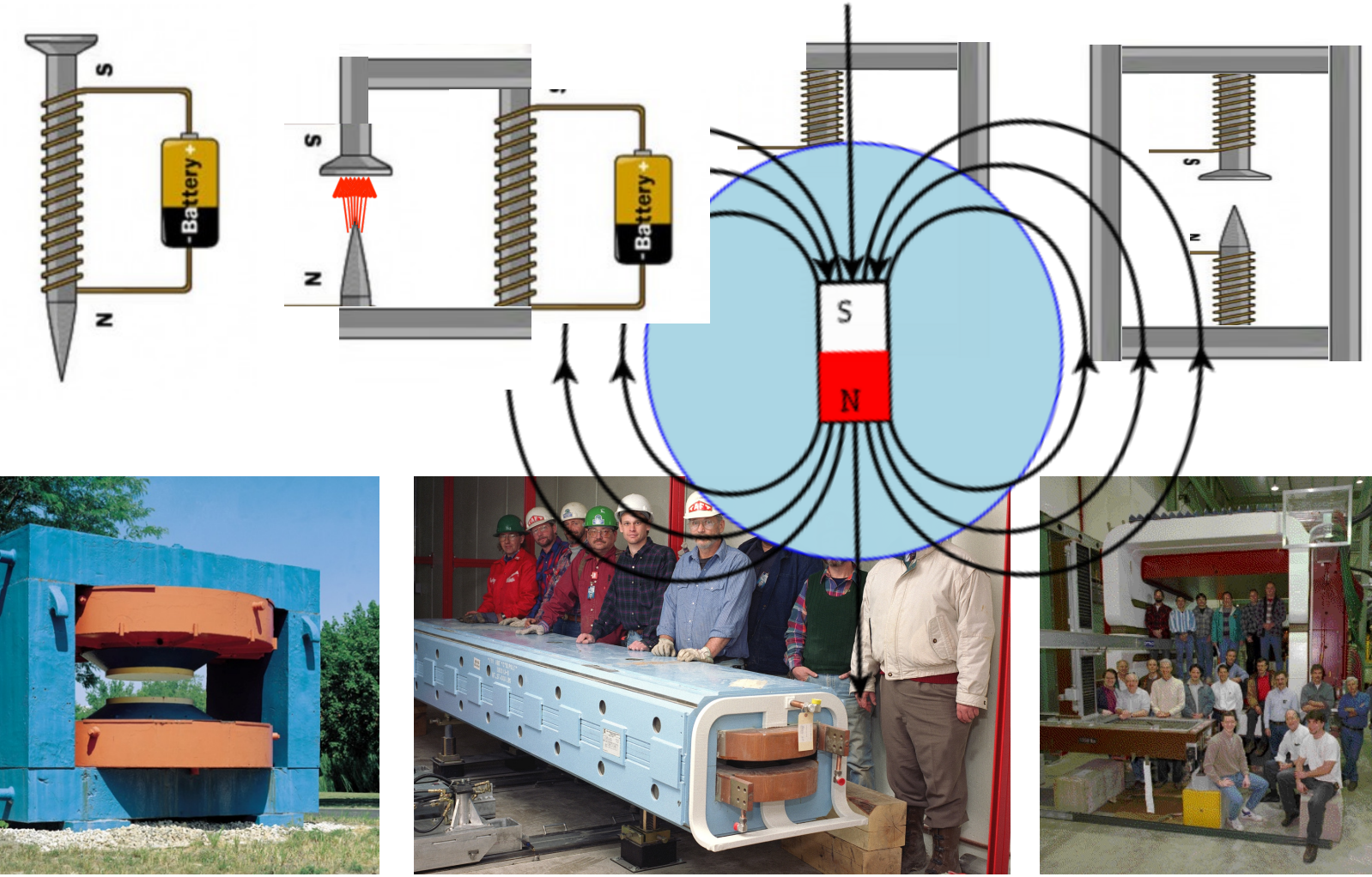


# Magnets make magnetic fields

- The magnetic field has a strength and a direction at every point in space.
- Think of little arrows everywhere.

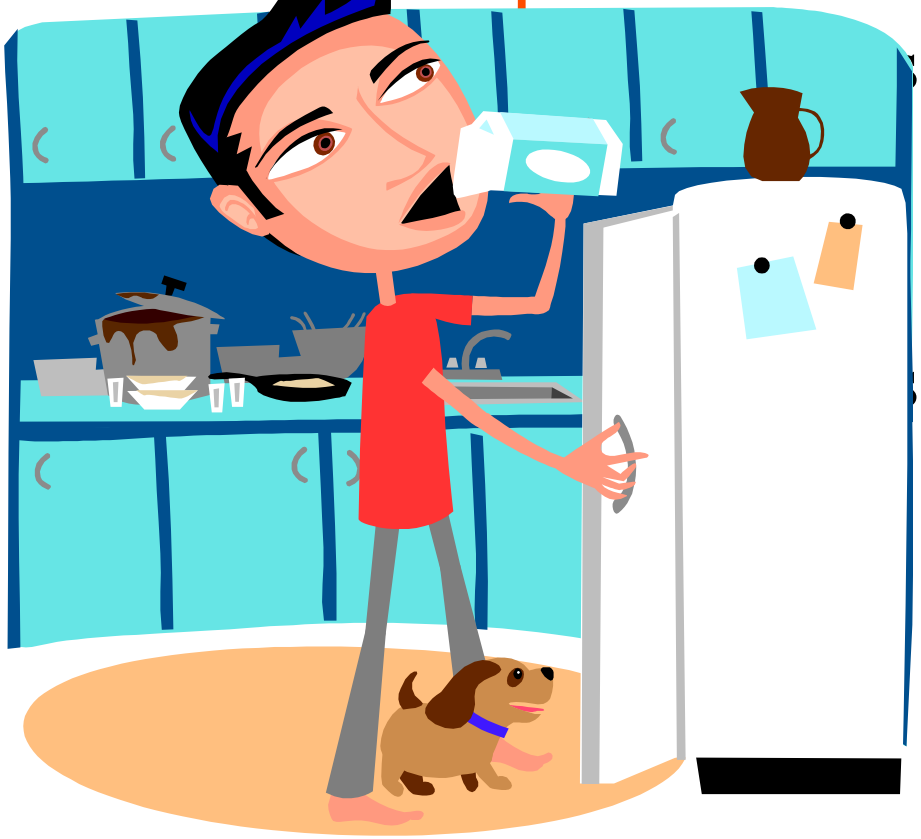


# How to make an electromagnet



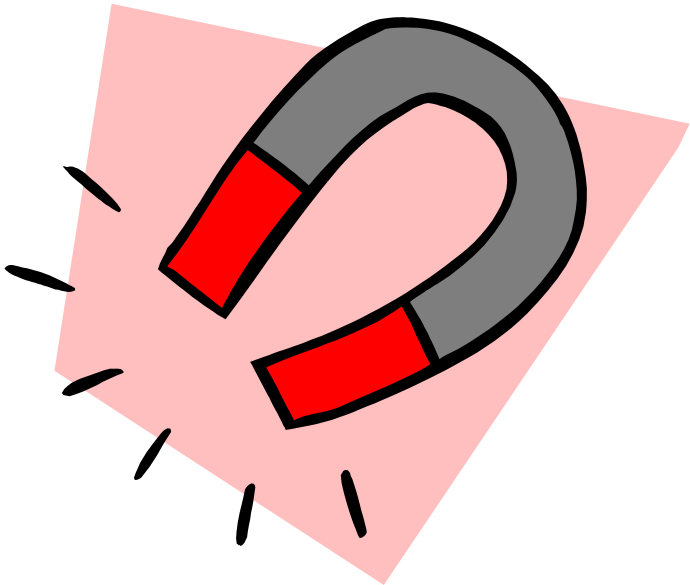
# Basic uses of magnetic fields

- Measure particles



s to analyze particles

s to steer beams where



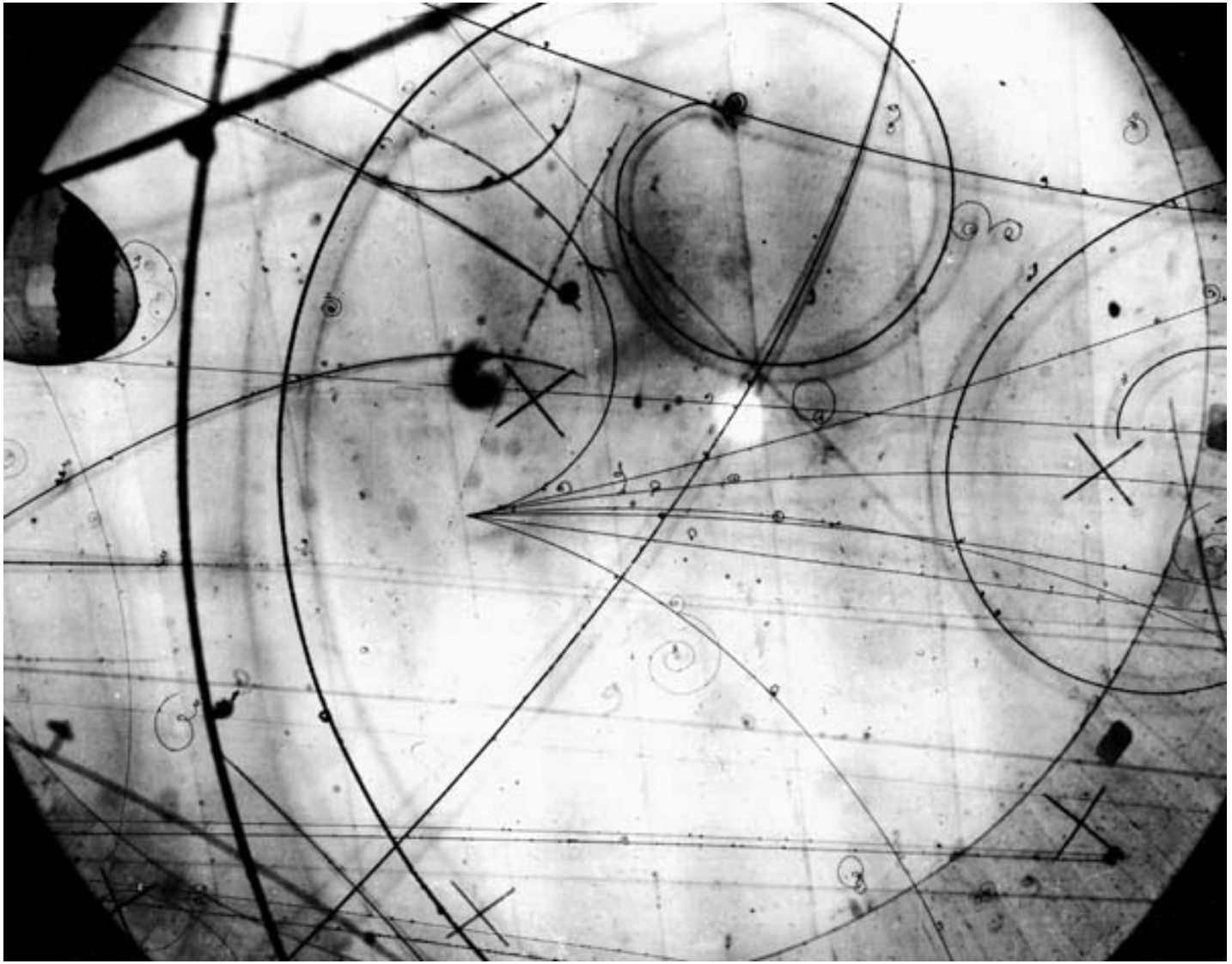
# A charged particle moving in a magnetic field feels a force

The force is sideways

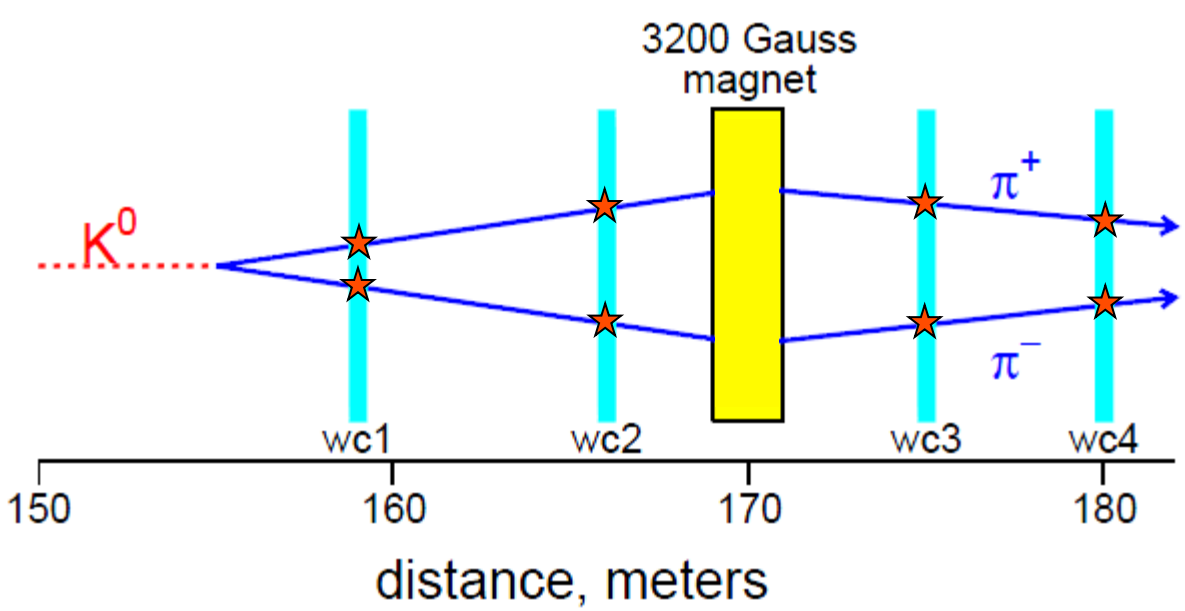
$\Rightarrow$ The particle bends in a circle

- Low momentum particle, small circle
- High momentum particle, big circle
- Strong magnetic field, small circle
- Weak magnetic field, big circle

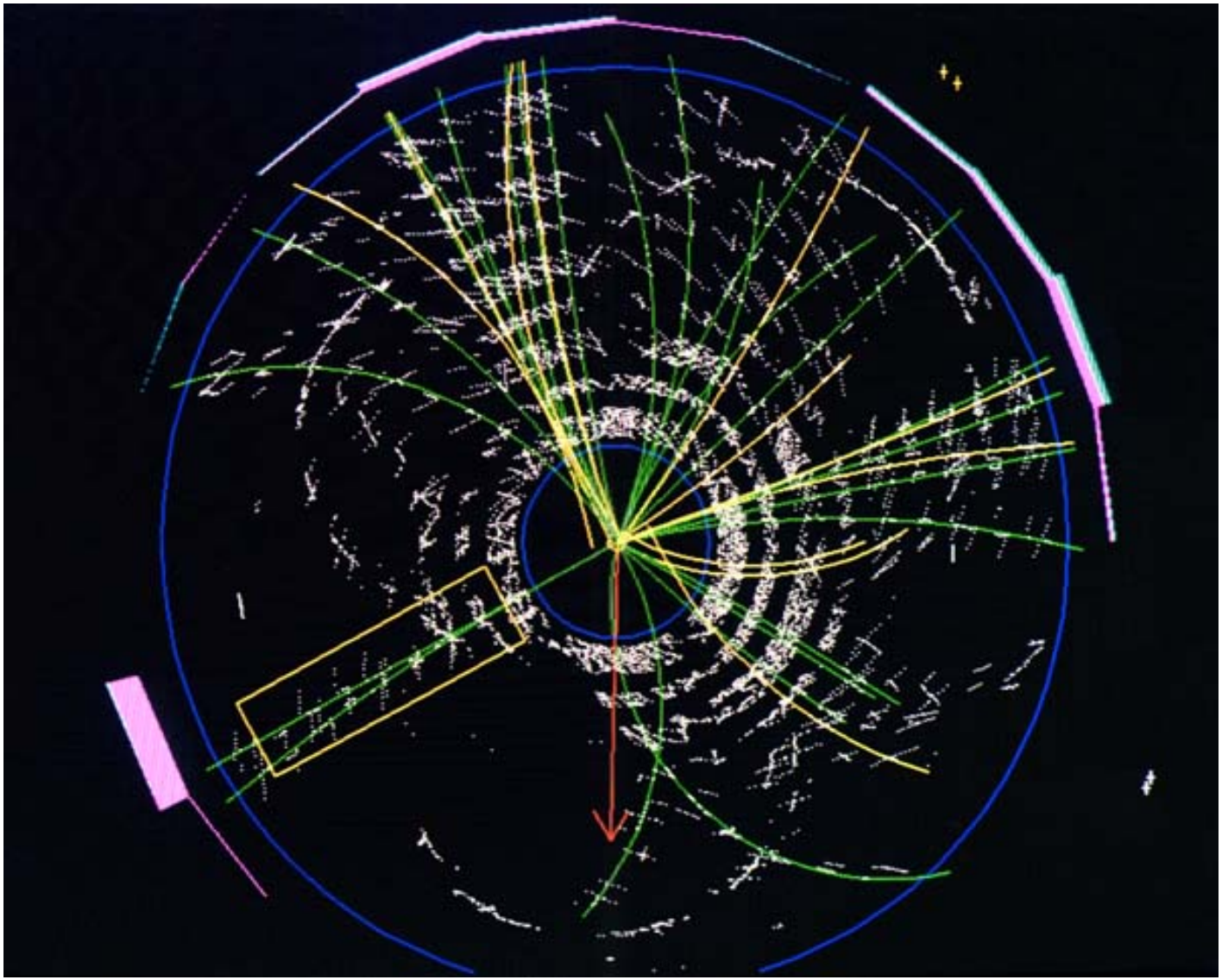
# Bubble chamber tracks



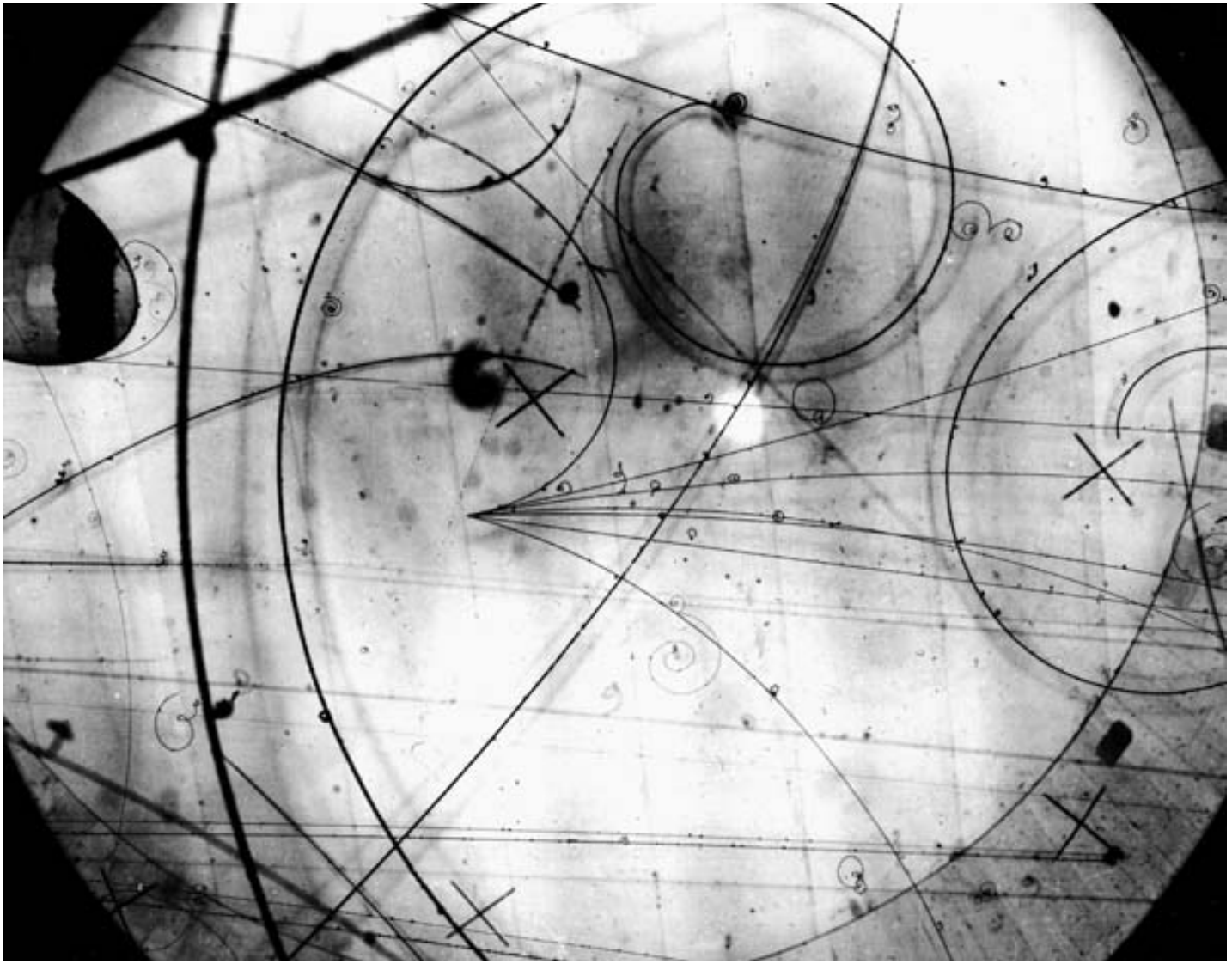
# Measuring bends with wire chambers



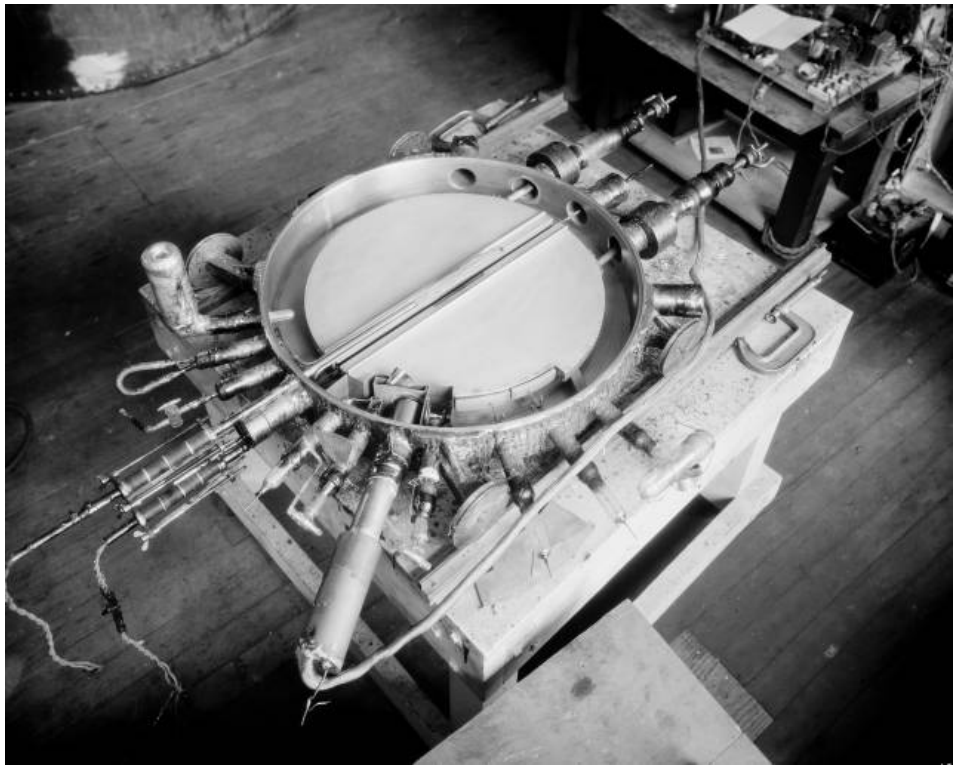

# Collider detector tracks (CDF)



# Bubble chamber tracks

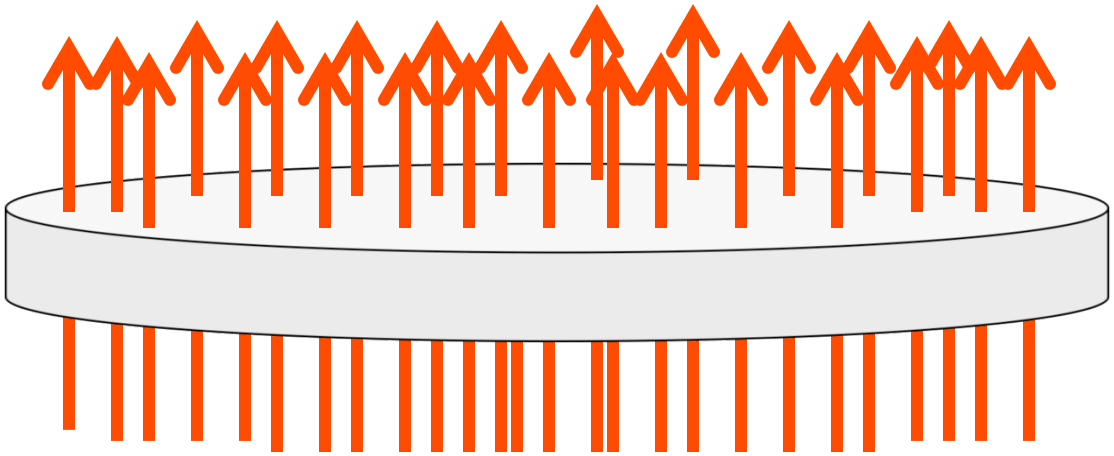


# Cyclotron Accelerator

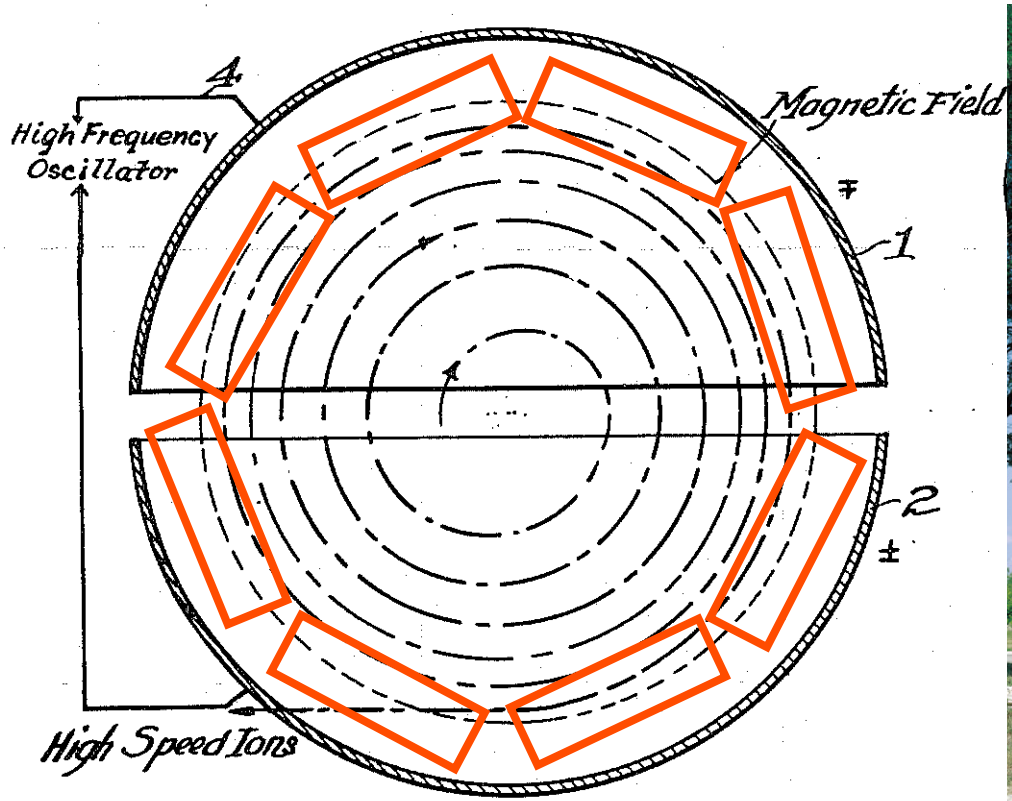


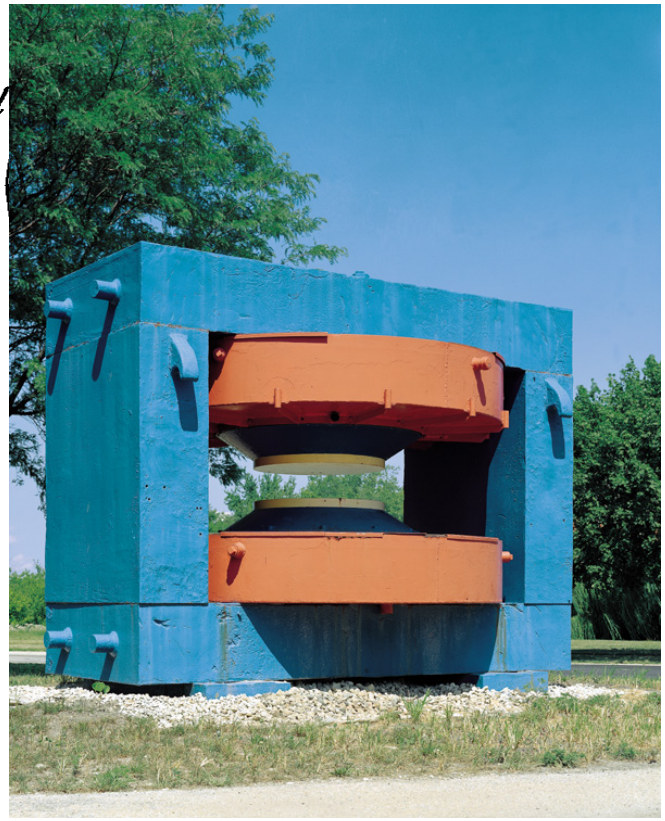
Ernest Lawrence

# Cyclotron Accelerator



# Cyclotron Accelerator

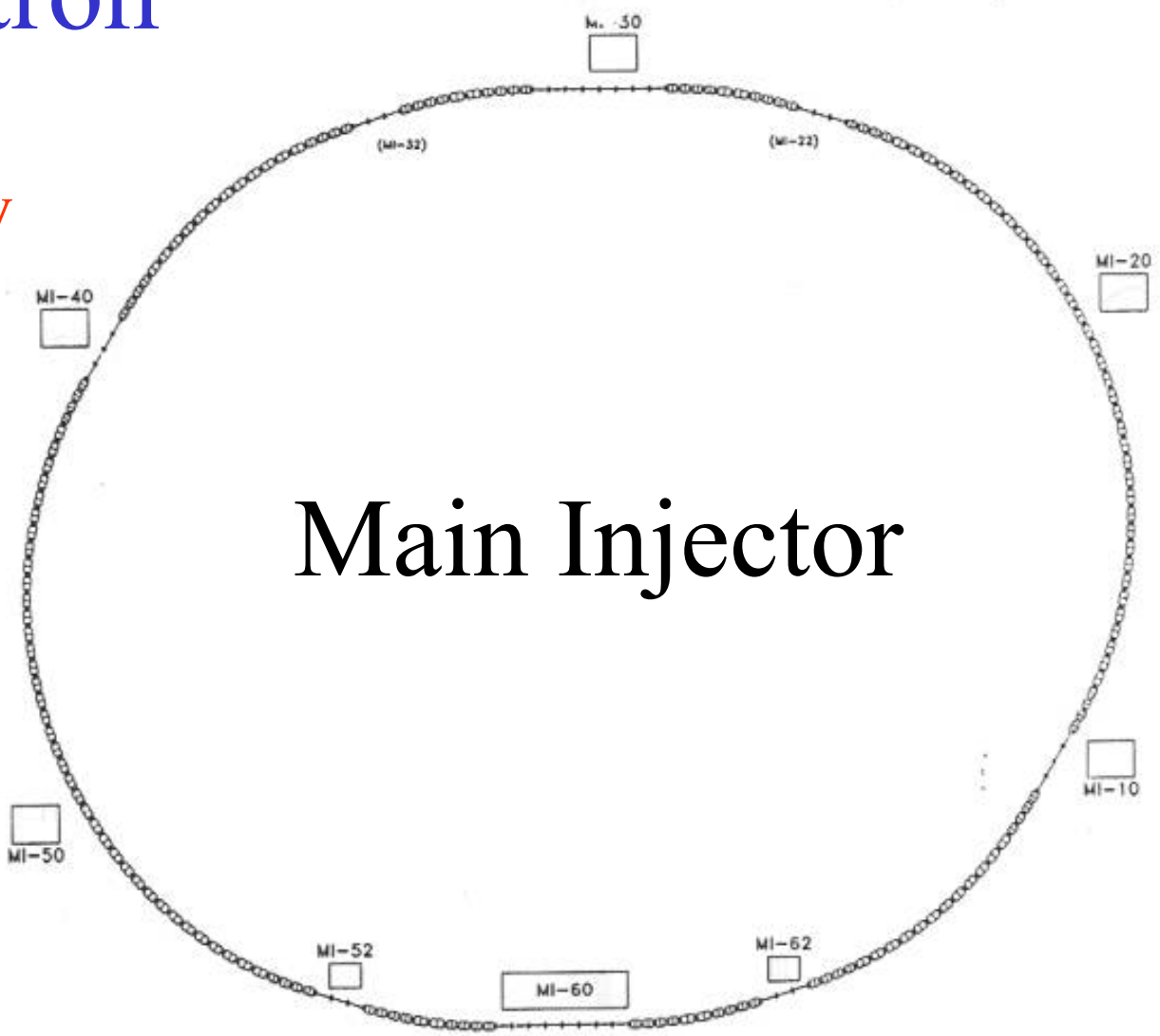


# SynchrotronAccelerator

# Synchrotron

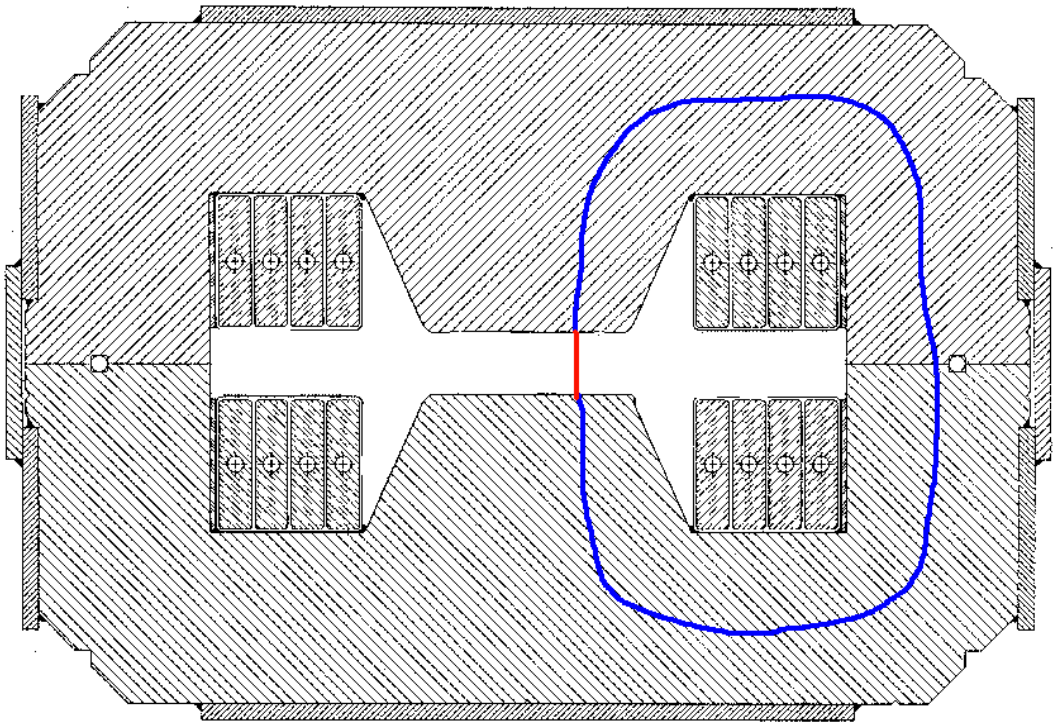
String together many long skinny magnets in a big ring.



# Magnets in Main Injector

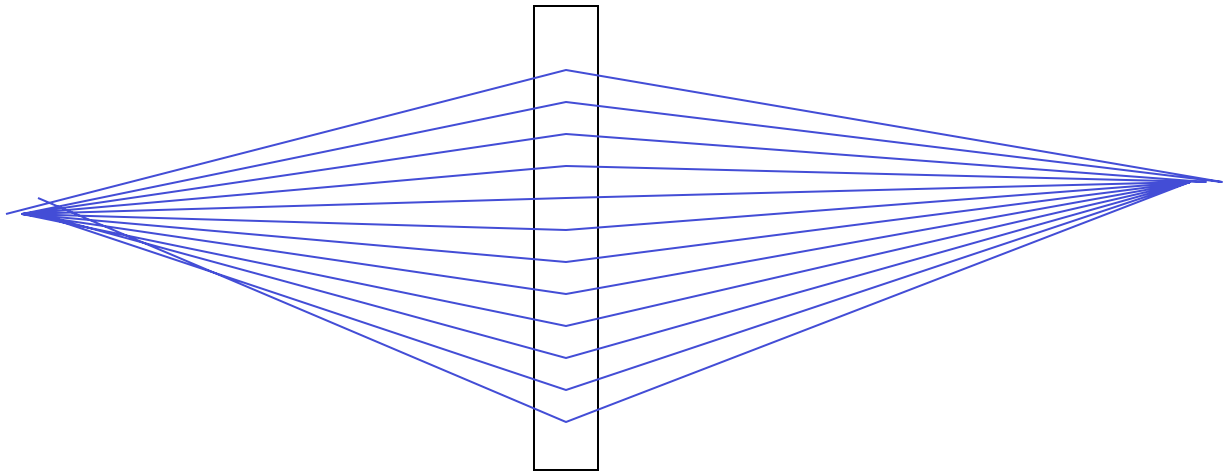
# A Synchrotron Magnet

# Ampère's Law

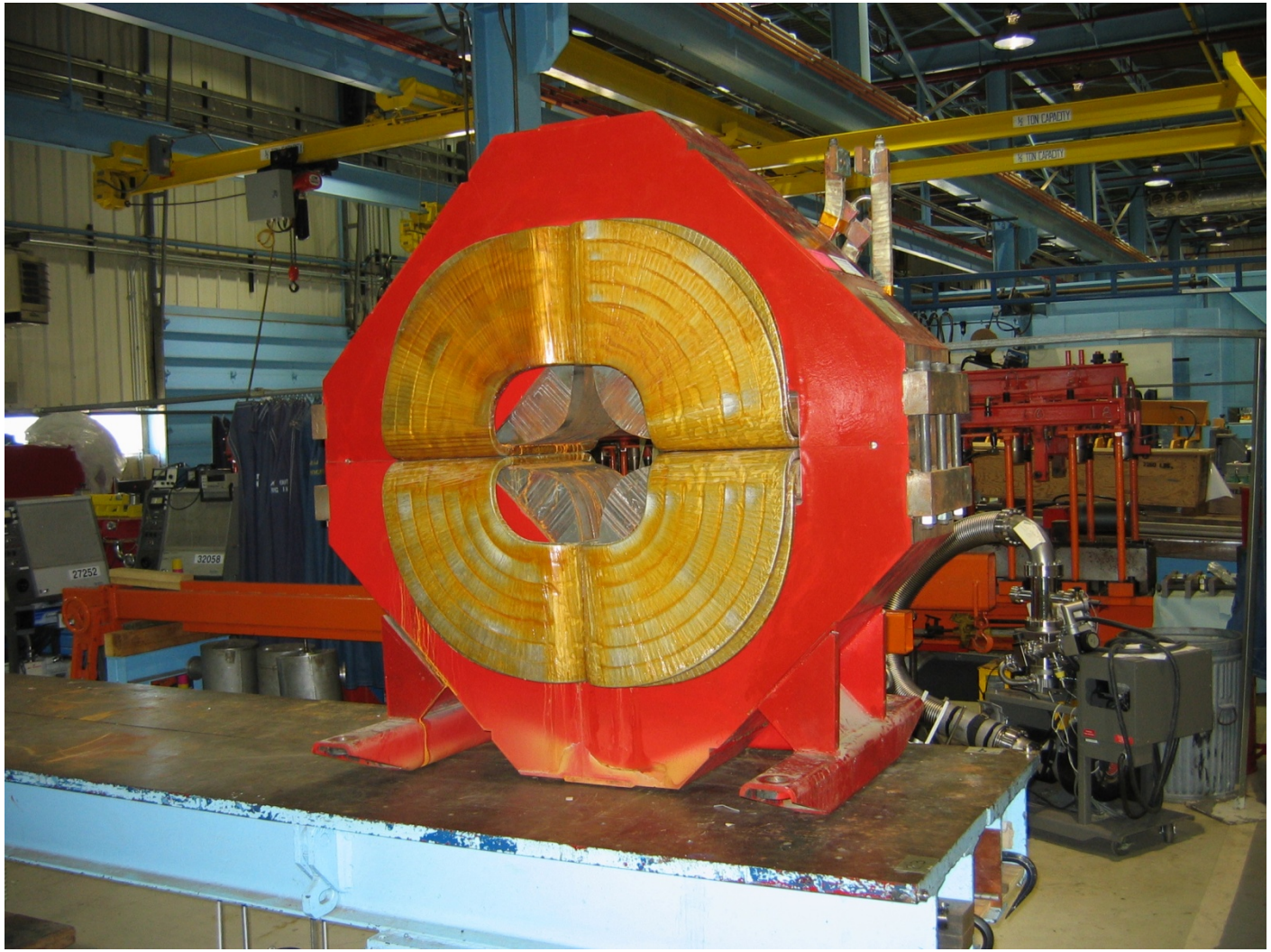


# Focusing magnets

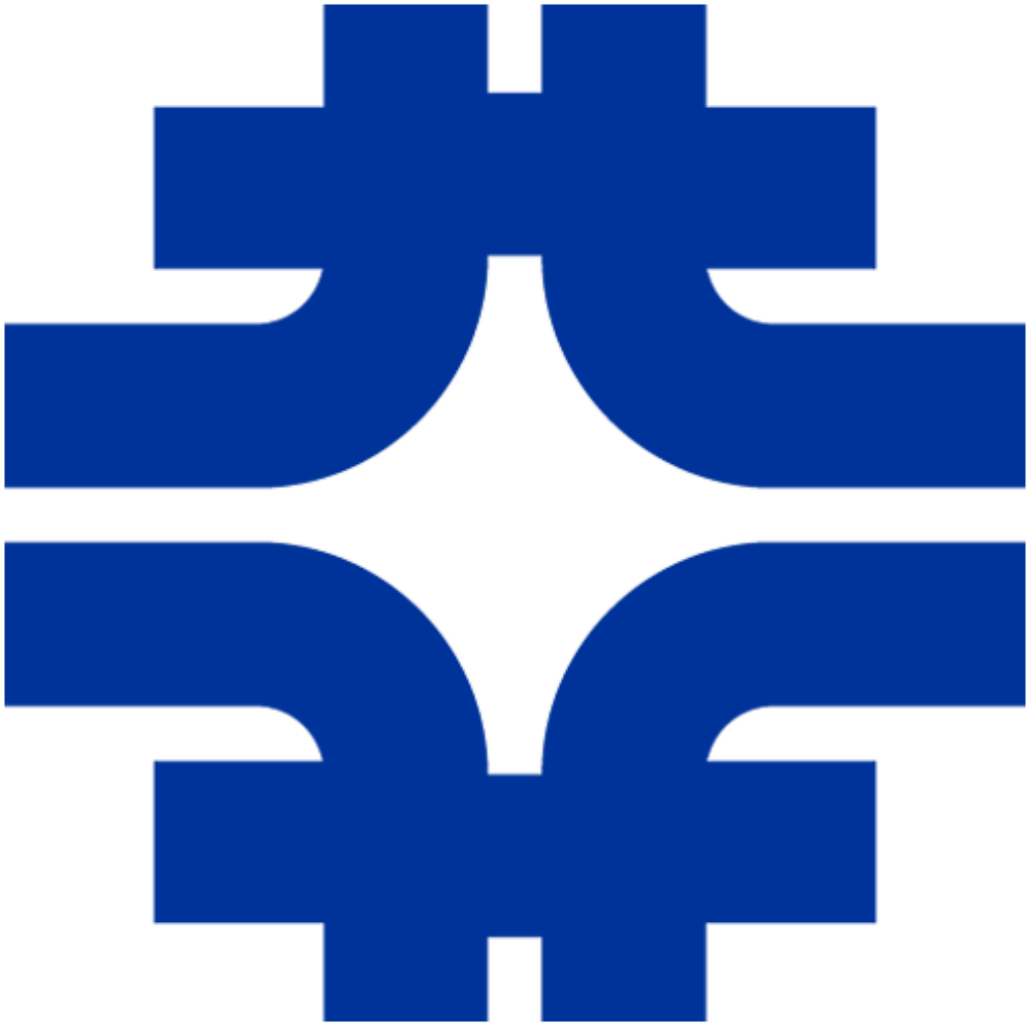
- Beam tends to spread out
- Must constantly focus the beam
- Special magnets do the job



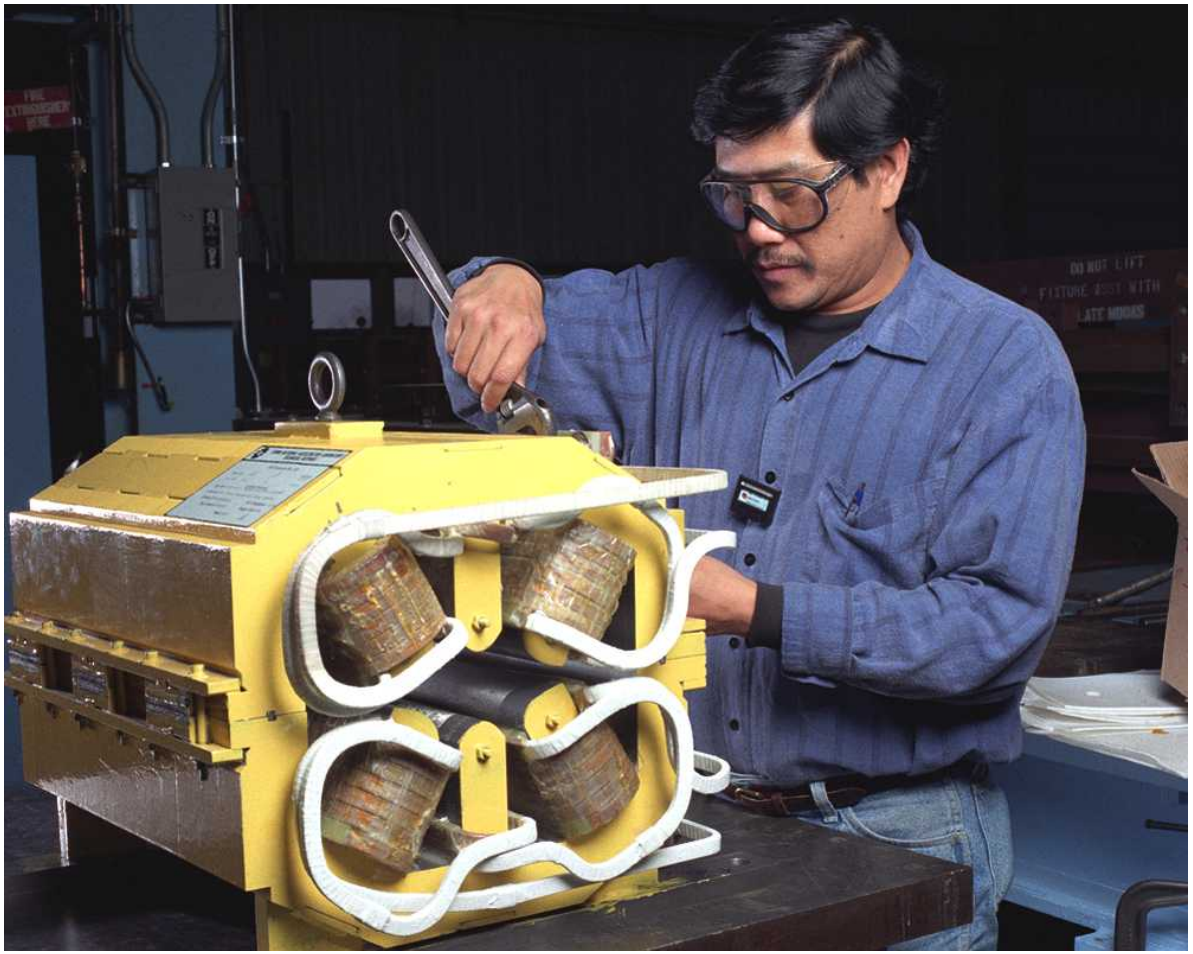
# Focusing magnet



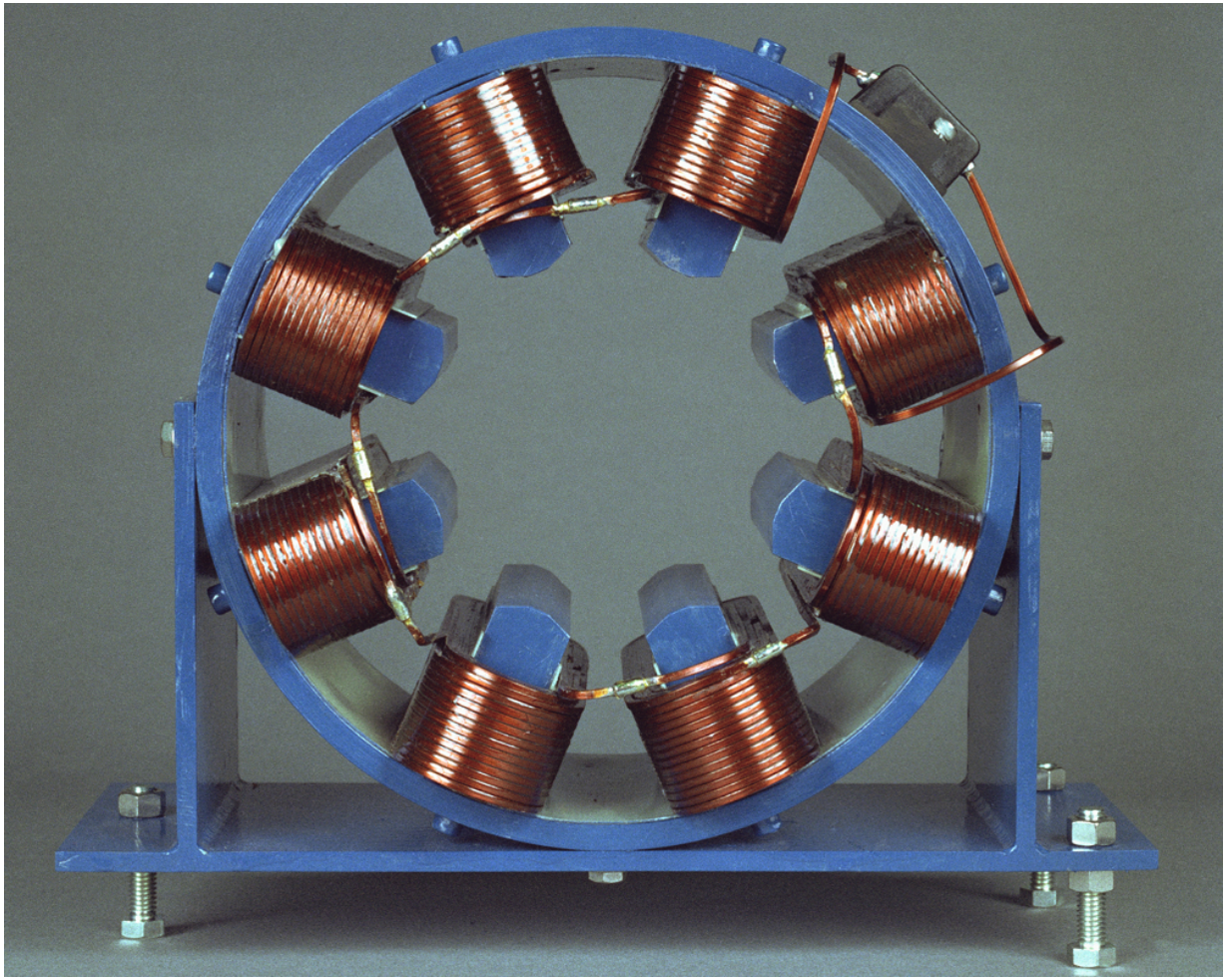
# Quadrupole Magnet



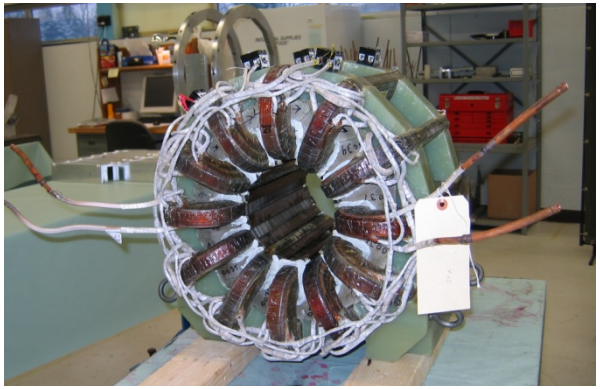
# Main Injector Sextupoles



# Octupole Magnet

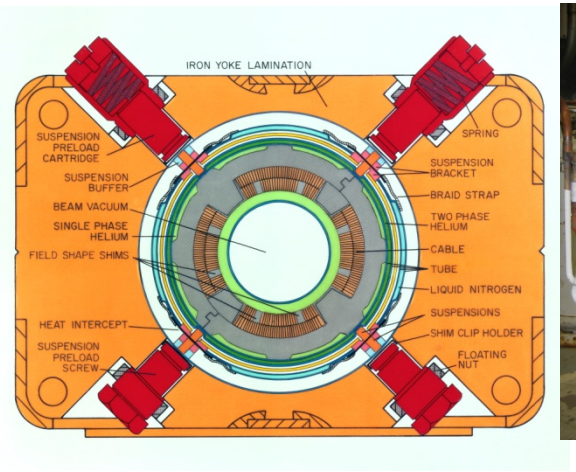


# Multiple Magnets in One

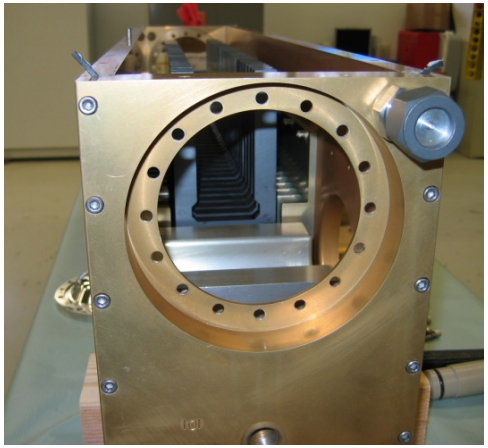


# Magnet work in Technical Division

- Design, build, refurbish, repair, and test magnets for current operations
- Develop even higher strength magnets for future projects





# Come visit us and see more

- **Employee Lunchtime Site Tours of TD**
  - **Tuesday, November 27**
  - **Thursday, November 29**
- **Sign up by e-mailing Sandra Charles <scharles@fnal.gov>**

# Even stronger magnets

- $M = E/c^2$
- Making higher mass particles requires more energy
- Higher energy requires stronger magnets
- Tighter focusing requires stronger magnets
- Stronger magnets require more electric current

# More electric current

What's the problem?

1. Use bigger wire
2. Cool the wire with water
3. Use superconducting wire!

# SUPERCONDUCTIVITY!!

Some materials lose all their resistance when they get very, very, very cold.

How cold?

About -450º F (only a few degrees above "absolute zero")

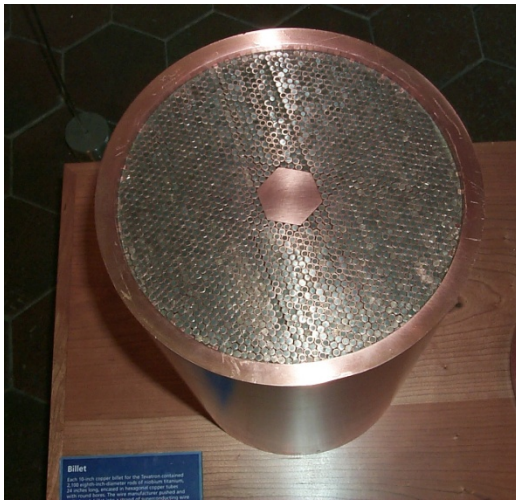
This is a good thing, but the materials can be hard to work with.

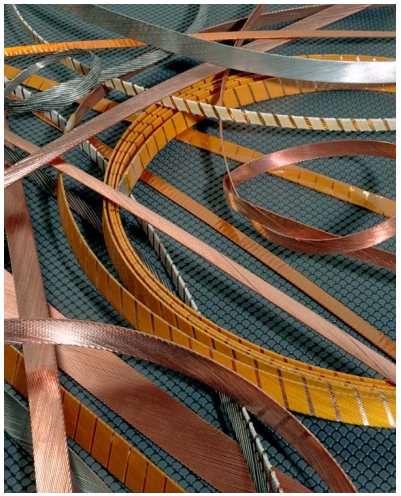
Niobium - titanium

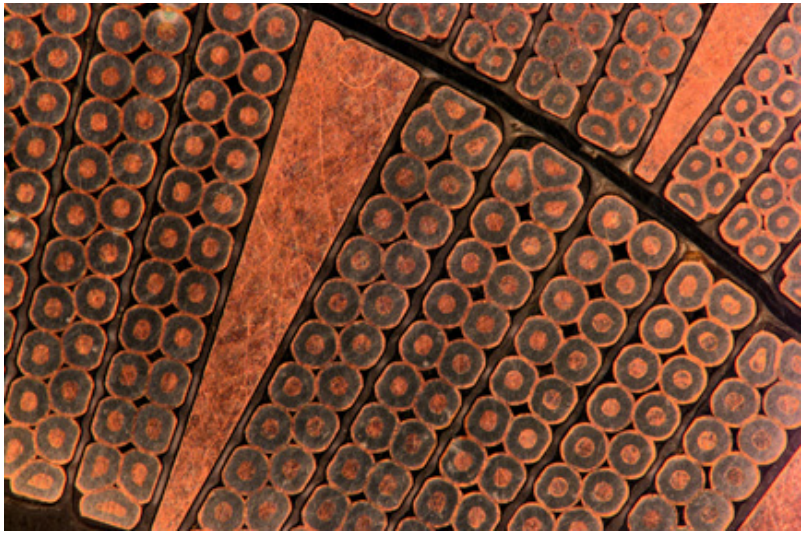
# Challenges

- Making the superconducting cable
- Shaping the magnetic field
- Cooling the magnet
- Keeping it safe
- *Et cetera*

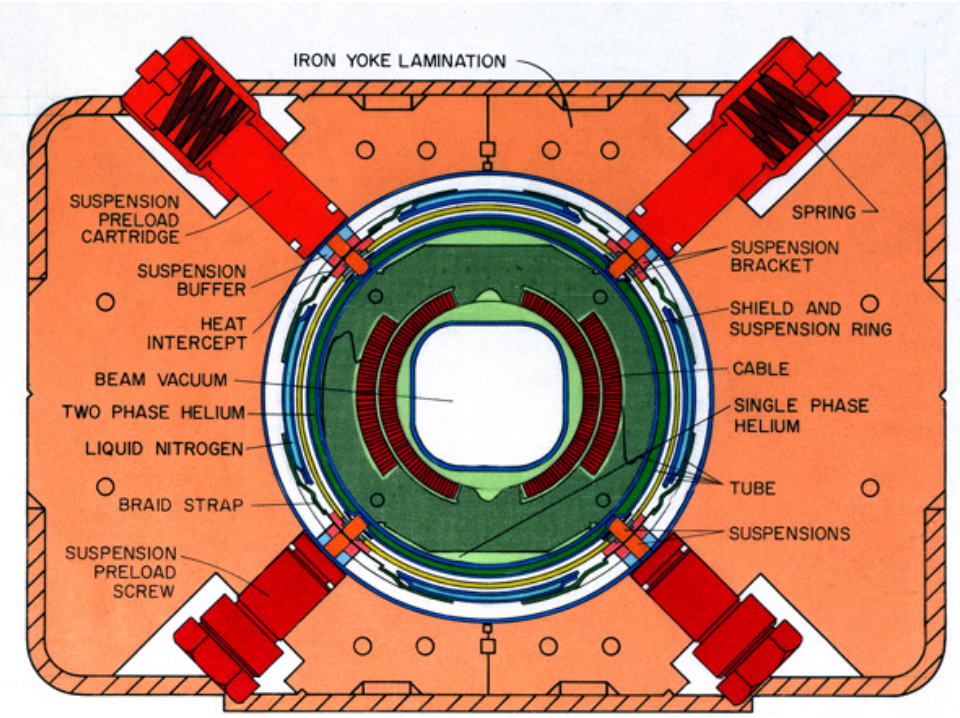
# Making Superconducting Cable

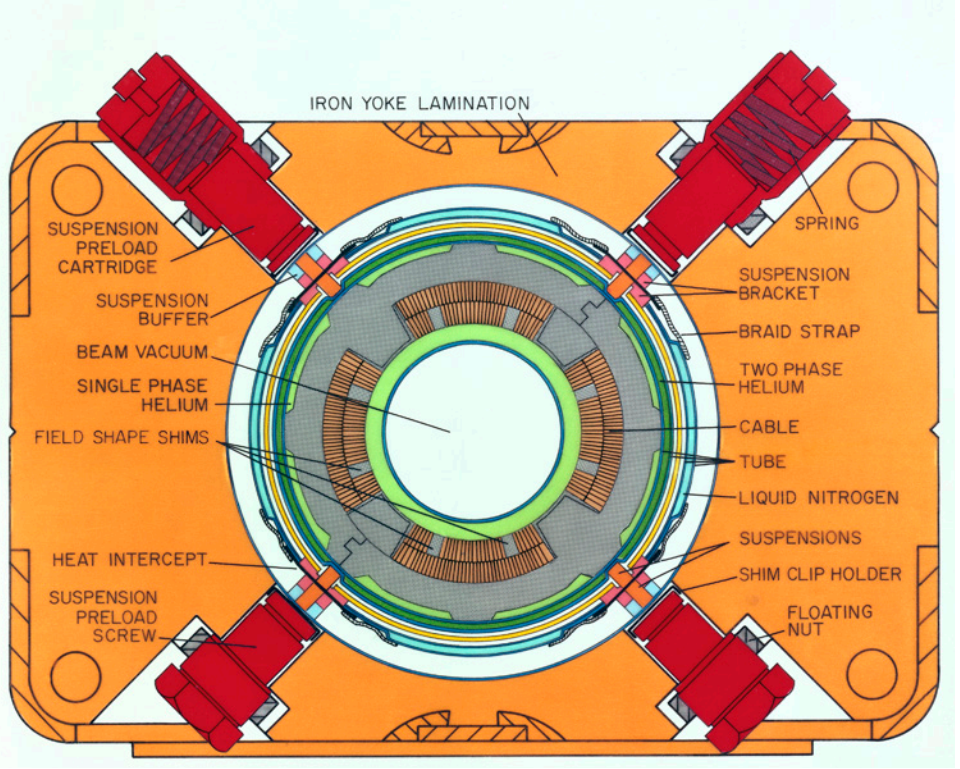


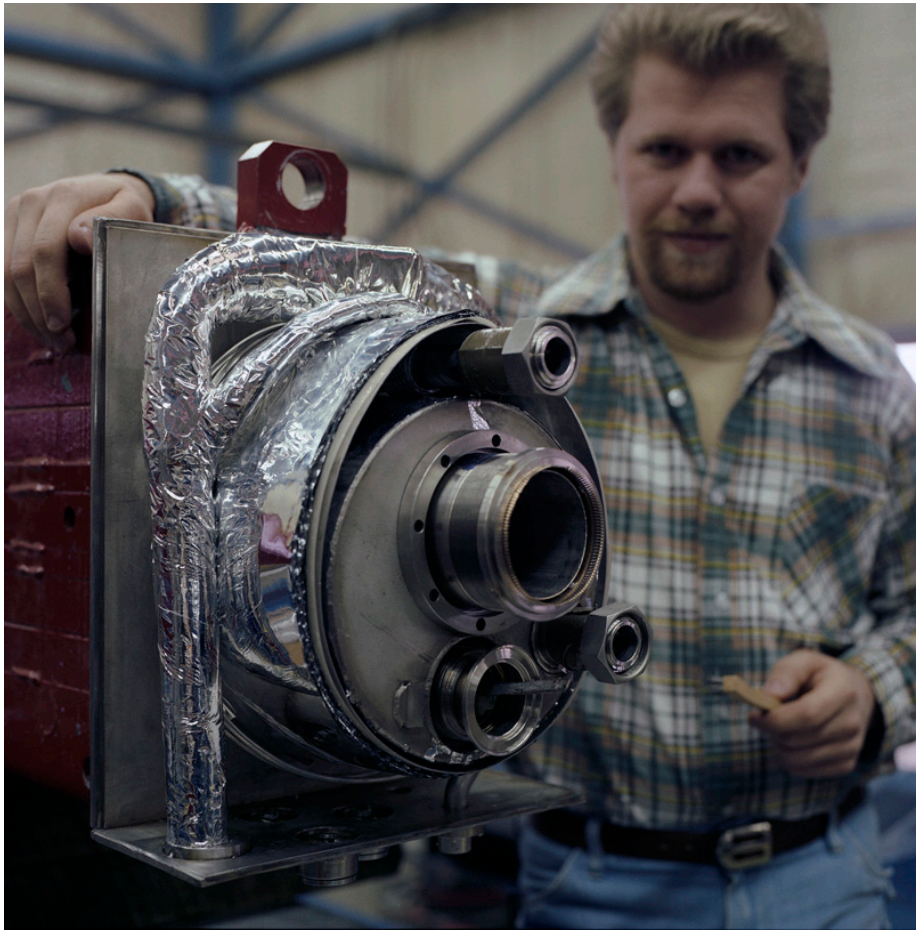


# Tevatron Magnet Cross Sections

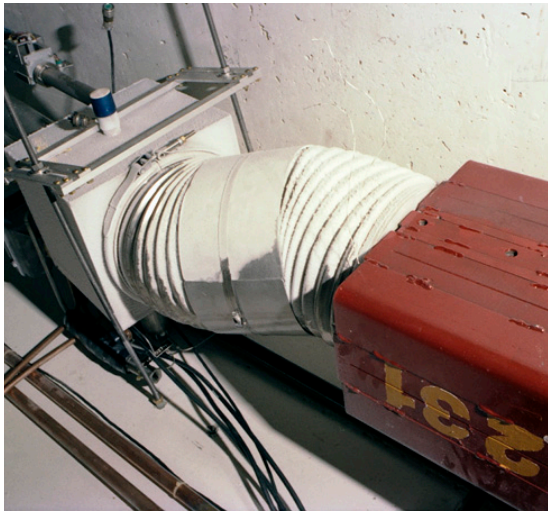


# Cool and insulate

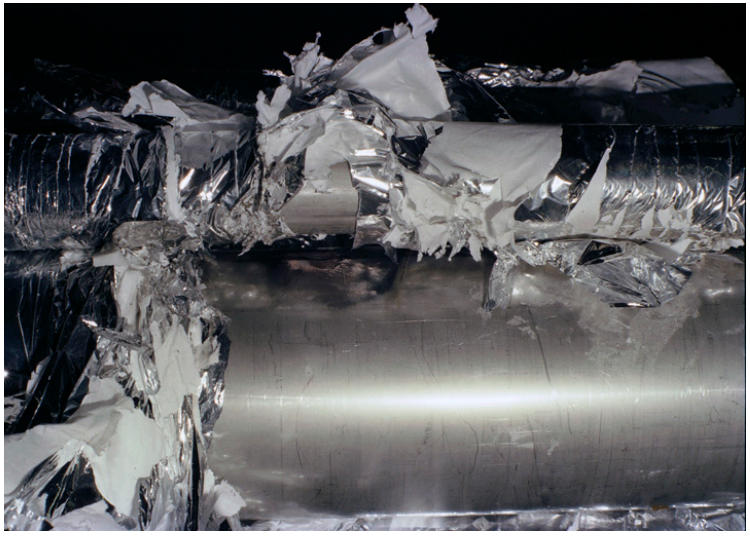



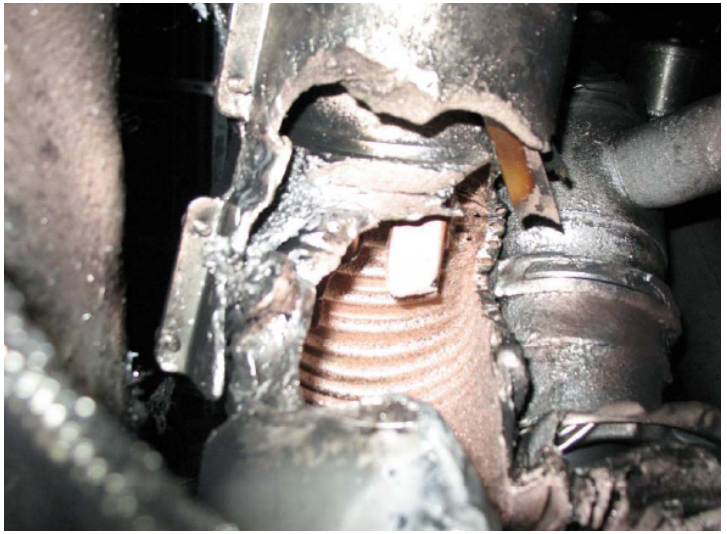
# Keep it safe



←Tevatron

LHC→





# Superconducting Materials (1)

- Every material has limits
- Niobium + titanium
  - Tevatron, LHC
  - Easy to work with, decades of experience
  - We have reached its limits

# Superconducting Materials (2)

- Every material has limits
- Niobium + tin ($Ni_3Sn$)
  - Next generation, LHC upgrades
  - Brittle, one decade of experience
  - Higher performance, but not unlimited

# Superconducting Materials (3)

- High Temperature Superconductors
  - Muon collider and beyond
  - Hard to work with, little experience
  - Developing the technology now